Factors Limiting Moose at High Densities in Unit 20A

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SUMMARY

We are monitoring moose (*Alces alces gigas*) reproduction, mortality, nutritional status, population size, trend, and composition in central Unit 20A (1.1 moose/km^2 in a 6730-km^2 area in 1998) with the goal of providing timely management recommendations to keep this high-density moose population from declining to low densities. Several authors have presented data indicating high-density moose populations should not be allowed to decline to low densities (Gasaway et al. 1983, 1992; Ballard and Larsen 1987; Bergerud and Snider 1988; Messier 1994; VanBallenberge and Ballard 1994). These authors' conclusions were based on the predominance of data showing that combined wolf (*Canis lupus*) and bear (*Ursus arctos* and *Ursus americanus*) predation can keep moose populations at low densities (0.04–0.4 moose/km^2 in areas >2000 km^2) for prolonged periods in Alaska, when human influence on wolves and bears is minimal. These low population densities for moose were described as well below food-limited densities and at densities that allowable harvests by humans were relatively low.

Ultimately, we hope to maintain moose at moderate to high densities without repeating the Alaska Department of Fish and Game (ADF&G) wolf control program that apparently helped moose increase to high densities in Unit 20A (Gasaway et al. 1983; Boertje et al. 1996). Moose steadily increased from 1976 though 1991, beginning with the initiation of ADF&G wolf control (1976–1982). Since 1991, population estimates indicate the population has been relatively stable, although yearling recruitment declined during the deep snowfall winters of 1989–1990 through 1992–1993.

Our management recommendations during this reporting period included improving habitat, particularly in the Tanana Flats, and temporarily eliminating harvest of female moose. Habitat improvement is prudent because nutritional status of Unit 20A moose is low compared to parameters measured at low population densities for moose. Eliminating harvest of females is prudent because calf, yearling, and adult survival and twinning rates declined during this

reporting period. Population modeling indicates the population declined 8% between May 1998 and May 1999.

This report summarizes data collected from central Unit 20A from 1 March 1996–1 July 1999 when moose density was high and snowfall was low. Fieldwork included initially collaring 45 random adult female moose in March 1996. We subsequently spent 2 calving seasons (1996 and 1997) collaring newborn moose to evaluate causes and rates of calf mortality and 3 springs (March 1997–1999) collaring 10-month-old moose to evaluate causes and rates of yearling and older moose mortality. All samples of collared moose older than neonates were equally divided between the Alaska Range foothills and Tanana Flats. Virtually all calving occurs in the Tanana Flats portion of the study area. We evaluated nutritional status of the moose population by measuring pregnancy and twinning rates of adults, pregnancy rates of yearlings and 2-year-olds, weights of newborn and 10-month-old calves, and rump-fat depths of adults using ultrasonography.

During this reporting period, we added studies of moose dispersal and moose browse use as part of a graduate student program conducted by CT Seaton. Studies of moose dispersal were previously conducted in Unit 20A by Gasaway et al. (1980) at low densities. We are interested in whether dispersal may have increased following increases in moose density. Browse studies were initiated to provide a baseline of information for comparisons with other areas and to assist in prioritizing habitat management activities.

Our observations support the hypotheses that Unit 20A moose exhibit relatively low nutritional status yet high survival, as predicted from the high population density for moose and relatively high ratios for moose:predator. Our most notable observations follow:

➢ A relatively stable population since 1991 of about 11,000–12,000 moose in Unit 20A using the 3 best population estimates (1991, 1996, and 1998). Annual harvest rates have increased during this period from about 4–7%. Low snowfall winters have occurred since spring 1993.

➢ An overall observed pregnancy rate among adult cows ≥48 months old of 80% ($n = 146$) and twinning rates of 3–31% during 1996–1999, compared to a 100% pregnancy rate and a 52% twinning rate in an adjacent low-density moose population in Unit 20E (Gasaway et al. 1992:24).

➢ Zero percent pregnancy rate among 22-month-old females ($n = 35$) in 1998 and 1999 and no rump fat, and 48% observed pregnancy rate among 36-month-old moose ($n = 21$) in 1999,

➢ Significantly lower weights of calves 10 months old in the Tanana Flats, compared to the Alaska Range foothills during each year from 1997–1999, but no differences in calf birth weights.

➢ Dramatically lower 10-month-old calf weights in our study area ($\bar{x} = 163$ kg, $n = 111$), compared with 10-month-old calf weights in an adjacent low-density moose population in Denali National Park ($\bar{x} = 207$ kg, $n = 8$).

➢ High calf survival (56% in the 1996 cohort and 52% in the 1997 cohort), compared to 5 other Alaska-Yukon moose calf mortality studies (19–42%) using radio collars, but reduced calf survival in the 1998 cohort.

➢ Wolves are the major predator on moose in Unit 20A in contrast to other study areas in Alaska and the Yukon where black and grizzly bears were the primary predators. Wolves killed about 1845 moose annually in Unit 20A during the low snowfall years of 1996–1997 through 1998–1999, compared to about 780 harvested by humans, 650 killed by black bears, 650 killed by grizzly bears, and 450 that die from other causes.

➢ A slight increase in the population is predicted using average mortality and productivity data from 1996–1999, but an 8% decline is predicted using 1998 data.

Primary management goals are to sustain a high opportunity to harvest moose and to keep the moose density above levels in which combined wolf and bear predation can maintain moose at low densities. To responsibly manage this population at high densities, we need to know to what extent malnutrition, predation, and harvest affect population trend, particularly during adverse weather. This information is necessary, for example, to estimate sustainable yields of moose and optimum numbers of moose during various weather patterns. Maximizing harvest of female moose during favorable weather may be important to prolonging the period of high moose density. However, we believe that great caution must be exercised in harvesting moose in this system. Gasaway et al. (1983) concluded that mortality from severe winters, hunting, and wolf predation were largely additive in Unit 20A in the early 1970s and that underestimating the impact of harvest can lead to a grave management situation.

Key words: management, moose, moose condition, mortality, predation, pregnancy, rump fat, survival, twinning.

CONTENTS

BACKGROUND

Moose (*Alces alces gigas*) in Unit 20A (Fig 1) are a world-class resource. Overall moose density in Unit 20A (0.85 moose/km^2 in a 13,000-km^2 area, Fig 2) is approximately 5–6 times higher than average moose densities in similar moose-wolf-bear systems where wolves and bears have been lightly harvested (Gasaway et al. 1992). High moose density in our study area apparently resulted in part from Alaska Department of Fish and Game (ADF&G) wolf control during 1976–1982. Also, Unit 20A has had favorable weather since 1975, except during 1989–1993, and most of Unit 20A has favorable moose habitat. Black (*Ursus americanus*)

and grizzly bear (*Ursus arctos)* predation is low compared to wolf predation (Gasaway et al. 1983:30, this study). Grizzly bears and possibly black bears were reduced in a portion of our study area by local harvests during the mid to late 1980s (Hechtel 1991; Reynolds 1994). Also, a second ADF&G wolf control program occurred during 1993 and 1994 to increase caribou (*Rangifer tarandus*) numbers, and private trappers usually harvest 15–25% of the autumn wolf population each winter (Boertje et al. 1996).

Our study area in central Unit 20A (6730 km^2, Fig 1) contains about 50% of the moose habitat in Unit 20A and about 67% of the moose. For example, in 1996 we found 30% higher moose density in our study area compared with the total Unit 20A moose density. From this and historical survey data, we surmise that the study area encompasses some of the best moose habitat in Unit 20A.

No examples exist in either Alaska or the Yukon where moose have maintained such a high density for long periods of time (>8 years) over a similarly large area (6730 km^2, Gasaway et al. 1992). We surmise from this that moose in our study area may eventually decline substantially from the combined effects of adverse weather, browse limitation, and uncontrolled wolf and bear predation (Gasaway et al. 1983, 1992). This was the case between 1965 and 1975 when the Unit 20A moose population declined from about 1.7–0.23 moose/km^2 (Gasaway et al. 1983). Ill-timed harvest of cow moose also contributed to the magnitude of this decline.

Maintaining moose in Unit 20A above the level at which predation can strongly limit moose would be a significant wildlife management achievement. For example, elevated consumptive and nonconsumptive uses of moose would be ensured, hopefully without repeated intensive predator control programs. Gasaway et al. (1992) concluded that moose densities are predictably low (0.04–0.42 moose/1000 km^2) where low harvest rates for wolves and bears prevailed for long periods in Alaska and the Yukon. Moose densities are higher in these same systems where humans significantly reduced predation.

Since the mid-1970s, Unit 20A has proven to be Alaska's most intensively managed area in terms of ADF&G costs to survey wildlife and reduce predation for promoting increased moose and caribou numbers. This management focus has broad local support, stemming primarily from a strong local tradition of hunting, awareness of the enhanced value of land with abundant wildlife, and gradual restrictions in hunting regulations elsewhere in Alaska. There is also widespread knowledge that Unit 20A moose densities and harvests were high during the 1960s, following federal predator control in the 1950s. Approximately 3000 hunters used Unit 20A annually since the late 1980s.

The 10-year decline of moose in Unit 20A, from about 22,000 in 1965 to about 2800 in 1975, taught us several important lessons (Gasaway et al. 1983). First, Unit 20A probably cannot sustain 1.5–1.9 moose/km^2 through adverse, deep snowfall winters when browse availability is reduced and energetic costs of obtaining browse are high. Second, wolves strongly impacted the declining moose population, as demonstrated by the wolf control program that coincided with a sustained 15% finite annual increase in the moose population (Boertje et al. 1996). Third, errors were made in managing moose in the late 1960s and early 1970s.

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Biologists mistakenly believed that predators killed only moose that would soon die from other causes.

Today, biologists have proven techniques for estimating moose population size and trend (Gasaway et al. 1986), and radiotelemetry allows biologists to investigate causes and rates of moose mortality and changes in reproduction. Also, the potential effects of wolf and bear predation are better understood.

A current theory on wolf predation in wolf-bear-moose systems predicts that, without periodic wolf control, wolves will increase and combined wolf and bear predation will be sufficiently high to reduce the moose population to a low level (Sinclair 1989; Messier 1994; Hayes 1995). Under this theory, moose will soon return to low densities.

Under an alternative theory, wolves may restrict the upper density and fail to reduce the moose population. For example, large wolf territory size may restrict wolf density well below the level that wolves alone can reduce an elevated moose population to low densities. Moose may live at elevated densities for a protracted period under this theory.

The most plausible scenario is that high moose densities will continue until adverse weather intervenes; at this time browse limitation and predation may exacerbate the decline to low levels. For example, a moose population living at an overly high density may suffer greater nutritional impacts from adverse weather (Peterson and Page 1983; Messier 1995) and could potentially be accelerated to low levels by intense predation, even when moose:wolf ratios are initially relatively high (Gasaway et al. 1983). Predation can accelerate declines because of increased vulnerability of prey and underutilization of carcasses (Peterson and Page 1983). Overly high moose densities vulnerable to browse limitation are, therefore, cause for concern among managers, especially if the public desires that managers repeatedly control predation.

To examine these potential scenarios, we are studying the reproductive and nutritional vigor of an elevated moose population, weather variables, and the causes and rates of moose mortality in an area where humans do not annually control predation (Boertje et al. 1988; Gasaway et al. 1992:Fig 9). Parameters previously correlated with moose nutritional condition include yearling and adult pregnancy rates, adult rump-fat depths, adult twinning rates, and chronology of calving (Boer 1992; Gasaway et al. 1992; Schwartz 1992; Stephenson et al. 1998). We will focus our research on calf and yearling survival and yearling reproduction because young age classes (calves and yearlings) are most sensitive to limiting factors, such as predation, adverse weather, or food limitation. Companion projects will study dynamics of associated wolf, caribou, and grizzly bear populations.

We hope to determine what factors combine to influence the moose population and what management strategies are prudent to keep moose from returning to low densities. For example, current management options include reducing harvest during autumns following reduced survival and increasing harvest and improving habitat to reduce the possibility of food limitation.

OBJECTIVES

➢ Review literature on these topics: 1) moose biology and ecology at high densities; 2) indices to nutritional status of ungulates; 3) models of ungulate population dynamics; 4) predator prey ratios in relation to population dynamics of moose, caribou, sheep (*Ovis dalli*), wolves, and grizzly bears; 5) predator/prey relationships in multi-prey, multi-predator systems; and 6) population and harvest data on moose, caribou, sheep, wolves, and bears in Unit 20A.

➢ Estimate and evaluate the usefulness of several reproductive and condition indices for moose in Unit 20A.

➢ Determine causes and respective rates of mortality among radiocollared moose of various age classes in Unit 20A.

A graduate student, Mark Keech, tested the hypotheses that a relationship exists between dam condition and mortality of calves and that a relationship exists between neonatal variables of condition and mortality of calves. Several papers were published as part of this Masters degree program (Appendices A, B, and C). A second graduate student, CT Seaton, is studying moose movements and dispersal rates and evaluating browse availability and food habits in the Tanana Flats and Alaska Range foothills.

STUDY AREA

This study is being conducted in the central portion of Unit 20A (6730 km^2, Fig 1) where moose densities are highest. This area is bounded to the north by the Tanana River, to the west by Tatlanika Creek, to the south by the crest of the Alaska Range, and to the east by the Little Delta River. Unit 20A was described previously by Gasaway et al. (1983) and Boertje et al. (1996).

METHODS

ADULT CAPTURE, CONDITION INDICES, RADIOTELEMETRY, AND MORTALITY

During 1–4 March 1996, we immobilized 22 adult female moose (>33 months old) in the Tanana Flats and 22 adult female moose and 1 yearling female in the Alaska Range foothills. During 10–13 March 1997 we recaptured 16 collared moose from the Tanana Flats and 12 collared moose from the Alaska Range foothills to reevaluate condition, and we captured 2 new adult female moose in the Tanana Flats. In March 1999 we radiocollared 4 new adult female moose in the Alaska Range foothills. We immobilized these moose with 4.0–4.5 mg (1.33–1.5 cc) carfentanil citrate (Wildnil®, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA) and 150–167 mg (1.5–1.67 cc) xylazine hydrochloride (Anased®, Lloyd Laboratories, Shenandoah, Iowa, USA), administered intramuscularly via a 3 cc projectile syringe (2.9 cm needle) fired from an extra long-range Palmer Cap-Chur® rifle (Douglasville, Georgia, USA). We injected 400–450 mg (8–9 cc) of naltrexone hydrochloride (Trexonil®, Wildlife Pharmaceuticals) intramuscularly to reverse the effects of carfentanil citrate. Only 1 of 74 immobilized moose died, and this moose was near death when darted. We used a Robinson

R-44 helicopter for moose capture during 1997–1999, and 2 Robinson R-22 helicopters in 1996.

During 11–12 March 1998 we recaptured 22 22-month-old moose that were initially collared as 10-month-old moose, and during March 1999 we recaptured 13 22-month-old moose. No mortality was observed using the following drug doses: 2.7–3 mg carfentanil citrate and 100–110 mg xylazine hydrochloride, delivered via a 2 cc projectile syringe (2.9 cm needle) and reversed with 275–300 mg (5.5–6 cc) naltrexone hydrochloride and 300 to 400 mg (3–4 cc) tolazaline hydrochloride, given intramuscularly except for 2 cc given intravenously.

When moose were immobilized, we 1) measured neck girth of moose, hindfoot length, and total length along the dorsal body contour from the hairless patch on the nose to the tip of the tailbone; 2) measured depth of rump fat on the rump via ultrasound (Stephenson et al. 1998); 3) extracted a canine tooth as needed to determine age from cementum annuli (Matson's Laboratory, Milltown, Montana); and 4) collected 50 cc of blood from the jugular vein. R Zarnke (ADF&G, Fairbanks) processed blood samples. Serum was analyzed for antibodies (ADF&G, unpublished data) and pregnancy-specific protein B (PSPB, Bio Tracking, Moscow, Idaho). In 1996 serum was analyzed for 22 constituents (standard blood-serum profile, Fairbanks Memorial Hospital) and the acute phase protein haptoglobin (L Duffy, University of Alaska Fairbanks). T Stephenson (ADF&G, Soldotna, Alaska) diagnosed pregnancy status using transrectal ultrasonography in 1996 to compare with PSPB levels in blood samples.

We deployed Advanced Telemetry Systems (ATS, Isanti, Minnesota, USA) radio collars (model 9-2D-3V). Pulse rate of collars doubled when collars remained motionless for 5 hours (motion sensing switch). We radiotracked adults daily in May and early June to detect newborn calves and listened to adult signals approximately monthly to monitor mortality rates. We used criteria and techniques described by Boertje and Gardner (1998) to evaluate causes of death.

SHORT-YEARLING CAPTURE, CONDITION INDICES, RADIOTELEMETRY, AND MORTALITY

We immobilized 17 short-yearling female moose (10 months old) in the Tanana Flats and 17 in the Alaska Range foothills during 9–19 March 1997. During 3 and 9 June 1997, we immobilized 4 yearling female moose (12 months old) in the Tanana Flats with a lighter drug dose because 4 calves died following capture in March. We immobilized March calves with 1.5 mg carfentanil citrate and 120 mg xylazine hydrochloride administered intramuscularly via a 2 cc projectile syringe (1.9 cm needle), fired from an extra long-range Palmer Cap-Chur® rifle. We injected 150 mg of naltrexone hydrochloride intramuscularly to reverse the effects of the carfentanil citrate.

During early March in 1998 and 1999, we immobilized 20 short-yearlings in the Tanana Flats and 20 in the Alaska Range foothills. No mortality was observed using the following drug doses: 1.2 mg carfentanil citrate and 60 mg xylazine hydrochloride, delivered via a 1 cc projectile syringe and reversed with 125–150 mg (2.5–3 cc) naltrexone hydrochloride and 200 to 250 mg (2.0–2.5 cc) tolazaline hydrochloride, given intramuscularly except for 1 cc given intravenously.

When moose were immobilized, we 1) measured neck girth and total length along the dorsal body contour from the hairless patch on the nose to the tip of the tailbone, 2) measured depth of rump fat via ultrasound (Stephenson et al. 1998), 3) weighed the moose with an electronic, calibrated strain gauge or dynamometer, using an R–44 helicopter to lift the moose, and 4) collected 50 cc of blood from the jugular vein.

We deployed ATS radio collars (model 9-2D-6V). Extra overlapping collar belting and an attached bungie accommodated growth of yearlings. We recaptured the yearlings and detached the bungie when moose were 22 months old. Pulse rate of collars doubled when collars remained motionless for 5 hours (motion sensing switch). We radiotracked yearlings approximately twice per month to monitor causes and rate of mortality.

NEWBORN CALF CAPTURE, CONDITION INDICES, RADIOTELEMETRY, AND MORTALITY

We monitored pregnant collared females daily from fixed-wing aircraft (Piper PA-18 Super Cub) between 14 May and 3 June 1996 and 16 May and 6 June 1997. We noted births during early morning fixed-wing flights and captured calves in the afternoon. We captured 46 calves between 14 May and 3 June 1996, 28 from radiocollared cows and 18 from unmarked cows. In 1997 we captured 45 calves, 25 from radiocollared cows and 20 from unmarked cows between 16 May and 9 June. We distributed collars both geographically and temporally to mimic the calving of collared cows.

We captured newborns using a Jet Ranger 206 helicopter during 1996. During 1997 we captured most newborns with an R-44 helicopter. Cow-calf pairs were usually in clearings that permitted landing within a few meters of calves, and disturbance from the helicopter was usually sufficient to frighten dams away from the capture crew. If the cow-calf pair was not in or near clearings, the capture crew (with radio communication) exited the helicopter in the closest landing area. The helicopter then hovered above the calf in an attempt to frighten the dam away. We monitored all captures from fixed-wing aircraft. Some calves could not be captured without undue risk to the capture crew. If a calf of a radiocollared dam could not be captured, we captured a substitute calf from an uncollared dam in the same area. Capture success was most dependent upon the skills of the helicopter pilot. We released calves in less than 5 minutes (even if data collection was not complete) to minimize separation time. We used latex gloves and individual weighing and restraint bags (nylon bushel bags) to minimize transfer of scent. When twins were present, the capture crew captured and restrained both calves but processed only 1 and released both simultaneously.

We determined sex of calves and weighed calves by placing them in a bag and suspending them with a 25 kg Chatillon (Kew Gardens, New York, USA) spring scale. To estimate birth weights, we subtracted 1.6 kg for each day >0.5. This correction factor was based on regression models using weights of known age calves. Due to uncertainty in estimating age beyond 4 days, birth weights obtained from calves estimated to be older than 4 days were omitted from statistical analysis involving birth weights. We collected 3 cc of blood from the jugular vein. L Duffy (University of Alaska Fairbanks) analyzed serum samples for the acute phase protein haptoglobin during 1996.

During 1996 we deployed radio collars weighing 180 g each (ATS model 8C transmitters, 1.5 hr motion sensing switch) constructed from 2 layers of 10 cm PEG® (Franklin Lakes, New Jersey, USA) elastic bandage (Osborne et al. 1991). During 1997 we deployed radio collars (200 g) constructed from 4 layers of elastic bandage. The day following capture we visually radiolocated calves to assure the pair rebonded. Following visual confirmation of rebonding, we listened to calf signals to determine survival; flights were daily until 13 June and every other day until 30 June, after which the tracking interval gradually increased. We investigated mortality signals immediately using a helicopter. We used criteria and techniques described by Adams et al. (1995) and Boertje and Gardner (1998) to evaluate causes of death.

Eleven calves slipped collars from the 1996 cohort; 8 from collared dams and 3 from uncollared dams. We immediately censored calves of uncollared dams, but visually located collared dams to evaluate calf mortality rates. If the calf was not with the collared dam on 3 consecutive flights, we assumed the calf died. No calves from the 1997 cohort slipped collars.

STATISTICAL ANALYSES

Student's two-tailed *t*-tests for pooled variances were used to analyze tabular data unless otherwise specified. To identify potential relationships between 22 serum constituents (standard blood profile) and rump-fat depth, we used multiple regression models (α to enter and stay = 0.15). We used regression to evaluate whether relationships existed between calving date and rump-fat depth. We estimated survival rates for moose using Kaplan-Meier staggered-entry design for telemetry studies (Pollock et al. 1989). We used logistic regression to model the influence of the independent variables of neonate condition (birth weight, birth date, sibling status, and sex) on the dependent variable calf survival. We also used logistic regression to model the influence of the independent variables of cow condition (cow age, maximum rump-fat depth, midpoint rump-fat depth, and dam collaring location) on the dependent variable calf survival (Adams et al. 1995). Survival was broken down into 5 time intervals (1–30, 1–60, 1–140, 1–240, and 1–365 days); α for entry and inclusion into the model was set at 0.10 and a stepwise procedure was used. All analyses, with the exception of Kaplan-Meier estimates (Pollock et al. 1989) and *z*-test for proportions (Remington and Schork 1970), were done using the statistical program SAS (SAS Institute Inc., Cary, North Carolina, USA).

RESULTS AND DISCUSSION

ADULT FEMALE AGE STRUCTURE

A histogram of adult age structure (Fig 3) indicates the study population was well represented by young and middle-aged females in 1996. Mean adult female age was 6.8 yr ($s = 3.28$, $n = 45$) in 1996 using 1996 captures ($n = 44$) and a backdated 1997 capture. The oldest moose was estimated to be 13 years old (Matson's Laboratory).

REPRODUCTIVE INDICES

Given the high density of our study population and data summarized by Gasaway et al. (1992:Table 5), we predicted adult pregnancy rates of about 76–84% or lower as observed for moose populations with signs of nutritional stress from browse limitation. Our observations to

date support this hypothesis. Combined observations during the 1996–1999 calving seasons for moose ≥4 years old indicate a pregnancy rate of 80% throughout the study area, with annual values of 74–85% (Table 1).

We eventually want to test whether raising a calf significantly reduces the chance of a subsequent pregnancy, because pregnancy rates derived from PSPB values indicated a high annual variation in pregnancy rates, 98% ($n = 43$) in 1996 and 77% ($n = 30$) in 1997. Detecting pregnancy using transrectal ultrasonography and PSPB analyses gave identical results in 1996. However, daily observations during the calving seasons indicate lower actual productivity in the population and less variability than indicated using ultrasound or PSPB.

The spatial distribution of pregnancy rates indicated moose captured in the Tanana Flats were experiencing less favorable environmental factors in 1997, compared to moose in the Alaska Range foothills. Alaska Range foothills' moose experienced 100% pregnancy ($n = 12$ PSPB samples) in 1997, compared to only 61% pregnancy ($n = 18$) among moose captured in the Tanana Flats; this difference was significant ($P = 0.001$, z-test for proportions, $z = 3.39$). However, field observations from other years do not support the hypothesis that moose captured in the Tanana Flats have lower productivity compared with those from the Alaska Range foothills (Table 1).

Nutritional stress was indicated by the lack of calving among moose on their second birthday (Blood 1974). We tested for PSPB in blood from 35 yearling moose in March and 0 showed evidence of pregnancy ($n = 22$ in 1998 and 13 in 1999). Also, only 10 (48%) of 21 moose known to be 3 years old during May 1999 were observed with calves.

Low twinning rates in this high-density moose population generally indicate significant nutritional stress compared with other low- and high-density moose populations (Gasaway et al. 1992:Table 5). The observed 1996 adult twinning rate (32%, Table 2) falls within the range (23–90%) reported for moose from populations below K-carrying capacity (Gasaway et al. 1992:Table 5). In contrast, the 1997–1999 twinning rates (3–20%) fall within the range (1–25%) reported for moose from populations near carrying capacity (Gasaway et al. 1992:Table 5). Weather events are probably a major factor influencing annual differences in productivity of moose populations, and this relationship will be studied in more detail as more data become available.

We compared our twinning data with data belonging to management staff, who have conducted standard spring twinning rate surveys in the Tanana Flats for several decades (Table 2). On average, twinning rates derived from standard 1- or 2-day spring surveys have tended toward underestimating the twinning rate derived from daily observations of collared cows ≥4 years old. This reduced twinning rate can be partially explained by the inclusion of 3-year-olds, which produced 0 twins in 1999 ($n = 10$). We will calculate the expected twinning rates of moose ≥3 years old in future reports.

ADULT RUMP-FAT DEPTHS

Depth of rump fat is a potential index by which condition can be measured over time or among populations. During 1997 we observed significantly less rump fat on Tanana Flats

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cows than Alaska Range foothills cows (Table 3). These data indicate that Tanana Flats moose may be experiencing less favorable environmental factors compared to Alaska Range foothills moose in some years.

Our average rump-fat values are less than Stephenson (1995) reported for moose below K-carrying capacity on the Copper River Delta during March 1993 and 1994. However, the Copper River Delta has a much milder climate than Unit 20A. Comparable published March data from Interior Alaska and the Yukon are lacking at this time.

As expected, we found significant relationships between March rump-fat depths and reproductive status. Mean maximum depth of rump fat was significantly greater ($P = 0.001$, t-test) among pregnant versus nonpregnant adult cow moose (Table 4). Mean maximum depth of rump fat was also significantly greater ($P = 0.006$, t-test) for dams giving birth to twins versus those with singletons (Table 5). No relationship existed between rump-fat depths and cow age.

We also found that the fattest dams produced on average the heaviest calves. Regression indicated birth weight of singleton neonate moose was positively ($P = 0.0003$, $R^2 = 0.29$) related to March rump fat of their dam (Fig 4).

SHORT-YEARLING WEIGHTS AND RUMP-FAT DEPTHS

Short-yearlings weighed in the study area in March averaged only 163 kg ($n = 111$) versus 207 kg ($n = 8$) in a low-density moose population in adjacent Denali National Park (L Adams, Alaska Biological Services, USGS). In addition, L Adams weighed 12 6-month-old moose that averaged 195.7 kg in November 1998. Clearly, moose are exhibiting signs of nutritional stress from high density in Unit 20A.

Short-yearling moose weighed in the Tanana Flats have been significantly lighter (about 15 kg lighter) than those in the Alaska Range foothills each year (Table 6). Although virtually all calves are born in the Tanana Flats, calves that move to the Alaska Range foothills in summer or autumn must have access to improved food, relative to those remaining in the Tanana Flats. We have assigned the Tanana Flats a higher priority for improving moose habitat compared to the Alaska Range foothills, given the low calf weights in the Tanana Flats. Graduate intern and author CT Seaton is examining the timing of movements to the Alaska Range foothills and studying the winter-feeding ecology of moose in the Alaska Range foothills and the Tanana Flats.

No rump fat was detected on any 10-month-old calves sampled using ultrasonography ($n = 22$) in 1997. We know of no other published data on 10-month-old moose in Alaska or the Yukon with which to compare these data. However, several researchers are currently collecting these data (W Testa in Unit 13, ADF&G; L Adams in Denali National Park, USGS; and B Shults in the Noatak River, NPS).

NEWBORN CALF WEIGHTS

We expected birth weights to provide a relatively sensitive index to winter and spring maternal and range condition and that elevated birth weights would occur among the Alaska

Range foothills subpopulation, in part because these dams had significantly more rump fat than Tanana Flats dams in 1997. However, it appears that birth weights may provide only a nonsensitive relative index to winter and spring conditions. For example, we found no significant differences in newborn singleton or twin birth weights with regard to dam collaring location (Tanana Flats versus Alaska Range foothills, $P > 0.18$, t-test) or capture year ($P > 0.20$, t-test). Likewise, Ballard et al. (1996) found no increase in newborn calf weights following mild winter conditions.

Comparable data on calf birth weights from Interior Alaska and the Yukon are lacking at this time, making interpretation of birth weight data speculative. However, our calves weighed slightly more than captive calves born on a high plane of nutrition. Schwartz and Hundertmark (1993) reported mean birth weights of 13.5 kg for twin calves and 16.2 kg for single calves <24 hours old at the Moose Research Center on the Kenai Peninsula, Alaska. Our mean birth weights were 13.7 kg ($s = 1.6$, $n = 15$) for twins and 17.0 kg ($s = 2.6$, $n = 66$) for singletons.

As expected, twin calves weighed significantly less than singletons ($P = 0.0001$, males and females pooled, t-test) and female singletons weighed significantly less than males ($P = 0.005$, t-test, Table 7). Contrary to our findings, Schwartz and Hundertmark (1993) found no significant difference between male and female calf weights. To our knowledge, we have reported the first statistical difference in birth weights between male and female moose calves. Sexual dimorphism in weight of neonates has previously been reported for white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), and red deer (*Cervus elaphus*) (Verme 1989; Kucera 1991; and Clutton-Brock et al. 1981; respectively).

BLOOD PARAMETERS OF CONDITION

The acute phase protein haptoglobin in serum samples may be helpful in distinguishing stressed from nonstressed mammals (Duffy et al. 1993; Zenteno-Savin et al. 1997). No detectable levels of haptoglobin were present in any of our calf ($n = 43$) or adult ($n = 44$) serum samples from 1996.

With the blood obtained from adult female moose in 1996, we attempted to identify potential relationships between 22 serum constituents (standard blood profile) and rump-fat depth using multiple regression models. A model using creatinine and AST met all the necessary criteria but accounted for only 33.7% (adjusted R^2) of the variability observed (Keech et al. 1998). We conclude, at this time, that standard serum constituents are not useful indicators of rump-fat reserves in moose.

CALVING DATE AND CORRELATIONS WITH COW RUMP FAT, AGE, AND MORPHOLOGY

Reduced snow depths during winter 1995–1996 may have contributed to earlier calving in 1996 compared to 1997. During 1996, 35 births of radiocollared cows were observed between 12 and 27 May, median date of calving was 19 May, and the greatest number of births ($n = 5$) occurred on 20 May. During 1997, 29 births of radiocollared cows were observed between 14 May and 3 June, median calving date was 22 May, and the greatest number of births occurred on 20 and 21 May ($n = 3$ each). Cumulative proportions of calves born during each calving period are depicted in Figure 5. Historical data from this study area indicate these are

typical moose calving dates. Only following adverse winters with deep snow has calving in this area been delayed until June (ADF&G unpublished data).

If adverse winter weather can delay calving or if poor autumn condition delays conception, we would predict that dams with the earliest births might have the greatest March fat reserves or body size. As expected, regression indicated a significant (P = 0.0398) negative relationship (slope = -1.355) between calving date and maximum March rump-fat depth. For this model we tested for an interaction between maximum March rump-fat depth and year but did not find any interaction (P = 0.5488). Therefore, we pooled years giving the model a common slope but separate intercepts. Data are needed following adverse winter weather to further study this relationship.

NATURAL MORTALITY AND HARVEST AMONG MOOSE OLDER THAN CALVES

Adult natural mortality varied from 7–21% annually during this study (Table 8). No mortality was observed among 24 2-year-olds during May 1998 through May 1999. Gasaway et al. (1983:24) previously reported a lack of mortality among young adult age classes in this moose population during 1973–1978. Yearling mortality rates averaged 13% during 1997–1998 and increased to 33% during 1998–1999.

Wolf predation was the major cause of death among adult and yearling moose. Of 14 adult death sites visited, 10 (71%) adults were killed by wolves, 1 (7%) was killed by a grizzly bear, and 3 (21%) died from factors other than predation. Of 20 yearling death sites visited, 14 yearlings (70%) were killed by wolves, 4 (29%) were killed by bears, and 2 (10%) died from other factors.

Hunters took a nominal harvest of cows in the study area during September 1996, 1997, and 1998. During the first legal cow harvests since 1974, the department issued 300 drawing permits annually with 65–70 cows reported harvested each year. The 1996 and 1997 reported bull harvests totaled 610–625 for a combined reported annual harvest rate of 5–6% of the prehunt population. The annual harvest rates totaled 6–7%, if we multiply the reported bull harvest by 1.15 to account for unreported harvest and mortally wounded moose that were lost (Boertje et al. 1996). Using similar methods to estimate total harvest, Boertje et al. (1996) documented a 4% average annual harvest rate in Unit 20A during the previous 20 years. Regulations prohibit cow harvests in Unit 20A during 1999 because of declining survival rates of calf, yearling, and adult moose and lower than expected estimates of population size (Table 8, Fig 2).

CALF MORTALITY

The 1996 and 1997 radiocollared newborn calves experienced the highest annual survival rates (52–56%, Table 8) among Alaska-Yukon moose calf mortality studies conducted to date. Previously reported annual calf survival rates were 19% (Larsen et al. 1989), 25% (Gasaway et al. 1992), 29% (Osborne et al. 1991), 32% (Ballard et al. 1991), and 42% (Franzmann et al. 1980) using similar techniques.

Unfortunately calf:cow ratios declined in Unit 20A in 1998 to the lowest observed since 1975 (Boertje et al. 1996). For calves per 100 cows ≥28 months old, we counted 33 in 1998, 40 in

1997, 47 in 1996, 52 in 1994, and 42 in 1993. In part because of this decline in calf survival, we proposed to eliminate the 1999 cow harvests in Unit 20A.

In the final report we will compare the mortality rates of singleton calves among studies, because twin calves experienced significantly lower survival rates compared with singletons (P <0.05, log-rank test, Fig 6). Osborne et al. (1991) previously reported lower survival of twins. Protecting 2 calves from predators is probably more difficult than protecting a single calf (Stephenson and Van Ballenberghe 1995).

Predation was by far the major proximate cause of death in this and all previous moose calf mortality studies. Wolves killed more calves than either bear species in this study, while grizzly bears and black bears killed about equal proportions of calves (Fig 7). In previous moose calf mortality studies, either black or grizzly bears were clearly the major predator.

In addition to mortality detected using radiocollared calves, perinatal mortality apparently occurred in 7 (17%) of 42 births in 1996 and 3 (13%) of 23 births in 1997. These were births that were never observed during daily flights. Births were assumed based on pregnancy data, transrectal ultrasonography and PSPB analyses in March 1996 and PSPB analyses in March 1997. We define perinatal mortality as mortality during the first 24 hours after birth. Causes of these deaths are difficult to determine. Predation is probably only partly responsible for these deaths (Whitten et al. 1992; Boertje and Gardner 1998:14). For example, during helicopter flights, we observed 2 stillborn calves (1 each in 1996 and 1997), 1 from a set of twins and 1 apparently a singleton, both born to radiocollared cows.

We collared 91 newborn calves during 1996 and 1997 to estimate the mortality rate of calves we observed from fixed-wing flights. Eight calves died from capture-induced reasons (abandonment or trampling by dam following release), and we censored these from the analysis. One transmitter failed within a few weeks of deployment, and 1 failed a few months later.

RELATIONSHIP BETWEEN NEONATE CONDITION AND CALF MORTALITY

We studied the relationship between calf survival and birth weight, birth date, and sex for singleton calves for 1996 and 1997 data combined. No variables entered the logistic regression model for the survival interval 1–30 days. These data indicate that all calves are equally vulnerable to mortality factors common to this first month of life. However, for survival intervals age 1–60 and 1–140 days, birth weight entered the model ($P = 0.011$ and 0.007, respectively), indicating increased mortality of lighter calves (parameter estimates were -0.26 and -0.25, respectively). No variables entered the model for the interval 1–240 days. Keech et al. further analyzed these data (In press, Appendix C).

RELATIONSHIP BETWEEN ADULT CONDITION AND CALF MORTALITY

Preliminary analysis of the data supports the hypothesis that no relationship exists between dam condition (age, fat reserves, and collaring location) and mortality of their calves within the range of values observed. Neither dam age, fat reserves, nor dam collaring location entered the logistic regression model during any time interval. However, a weak indirect relationship between dam condition and calf survival may exist, based on the observed

relationship between dam rump fat and calf weight (Fig 4). More values are needed from more nutritionally stressed moose to further study this relationship. Keech et al. further discussed data (In press, Appendix C).

POPULATION MODELING

To derive a conceptual model of moose population dynamics in Unit 20A, we averaged data on annual estimates of population size (Fig 2), productivity, and mortality factors for the 3 low snowfall years of 1996–1997 through 1998–1999 (Table 9). The moose population derived is slowly growing, and wolves are the primary predator. Humans, black bears, and grizzly bears each kill about equal numbers of moose from the population annually. An 8% decline in the population is predicted using only data from 1998.

CONCLUSIONS

Moose in the study area are clearly nutritionally stressed compared to moose from areas of lower density in Interior Alaska. ADF&G is actively pursuing prescribed burns in Unit 20A to improve moose habitat.

Boertje et al. (1996) concluded that given the wide variation in previous snow conditions and effects of predation, the concept of a stable, long-term high density may be inappropriate in this study area. We have data from only 3 mild winters, and we expect to see much more variability in condition and survival following a winter of moderate to heavy snowfall.

Modeling exercises using data on productivity and mortality of the respective age classes indicate the population was probably slowly increasing from 1993 through 1997, but population surveys indicate a nearly stable population since about 1991. Graduate student CT Seaton will examine whether moose dispersal is occurring at a significant level.

A primary goal is to provide maximum sustained opportunity to harvest moose at moderate to high densities, but without repeating the previous wolf control programs. A priority is to keep the moose density from falling to densities that predation strongly limits human uses of moose (Gasaway et al. 1983, 1992). We hope to determine an optimum range of moose numbers for Unit 20A. Ideally, we want to see moose at high numbers but not so high that severe declines occur following adverse weather.

ACKNOWLEDGMENTS

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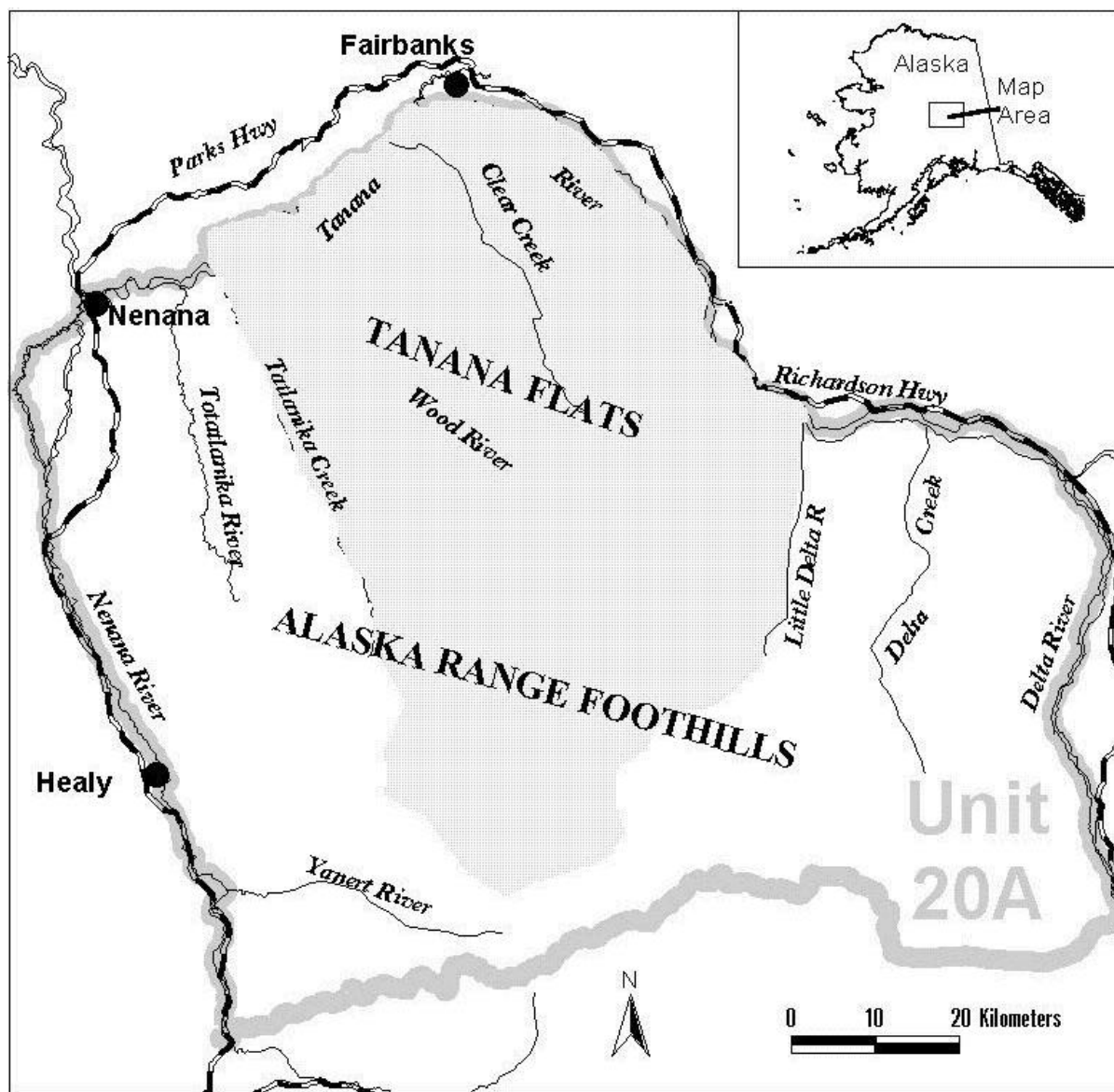Division of Wildlife Conservation

Figures

Figure 1   Shaded portion is the 6730-km^2 study area in central Unit 20A. About 67% of the moose in Unit 20A reside in the study area. Unit 20A contains about 13,044 km^2 of moose habitat.
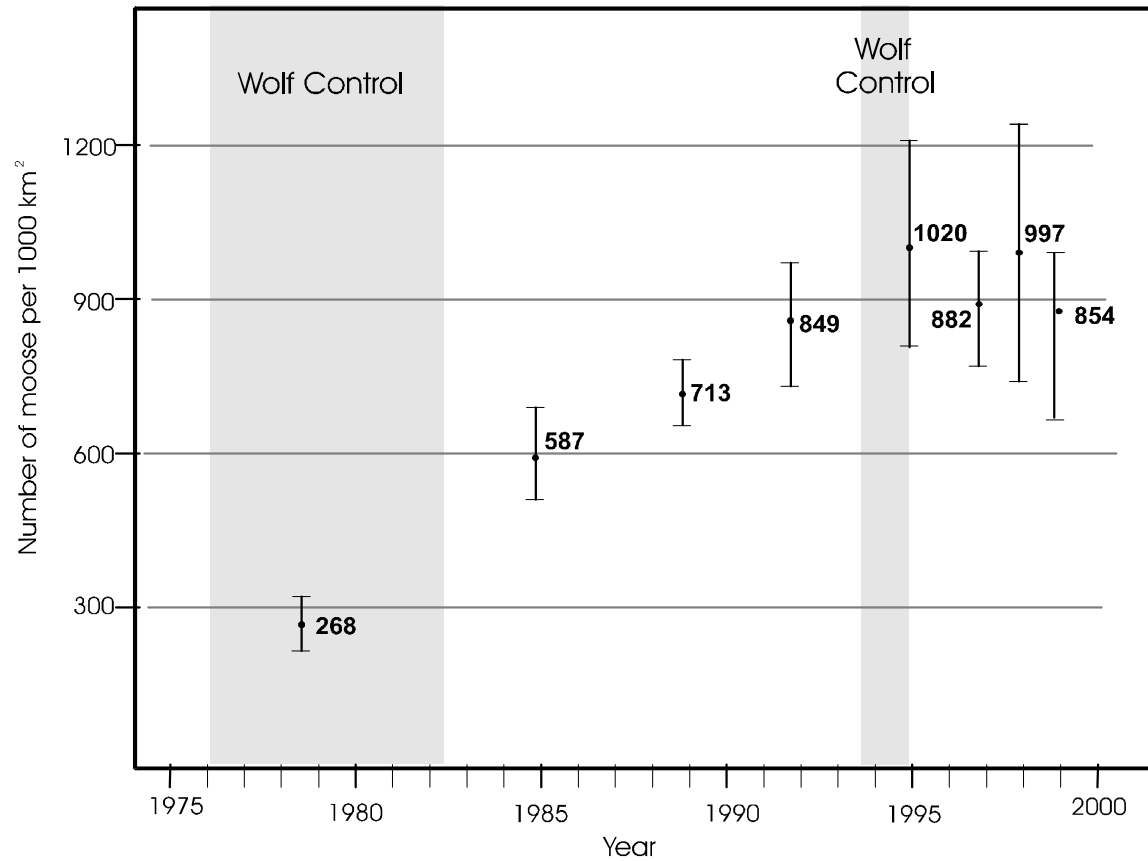
Figure 2 Moose density estimates (± 90% CI) in 13,044 km^2 of moose habitat in Unit 20A, Interior Alaska, 1978–1998. Data from 1978–1994 are described by Boertje et al. (1996). More recent estimates are from ADF&G files.
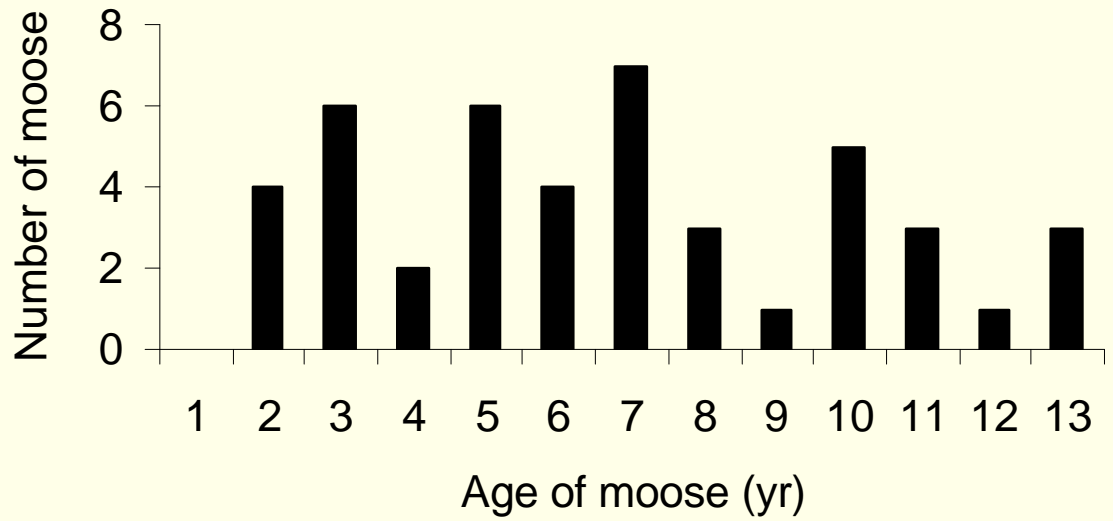
Figure 3   Age structure of 45 radiocollared moose ≥2 years old, central Unit 20A, March 1996. Data are from cementum annuli of canines (Matson's Laboratory, Milltown, Montana, USA).
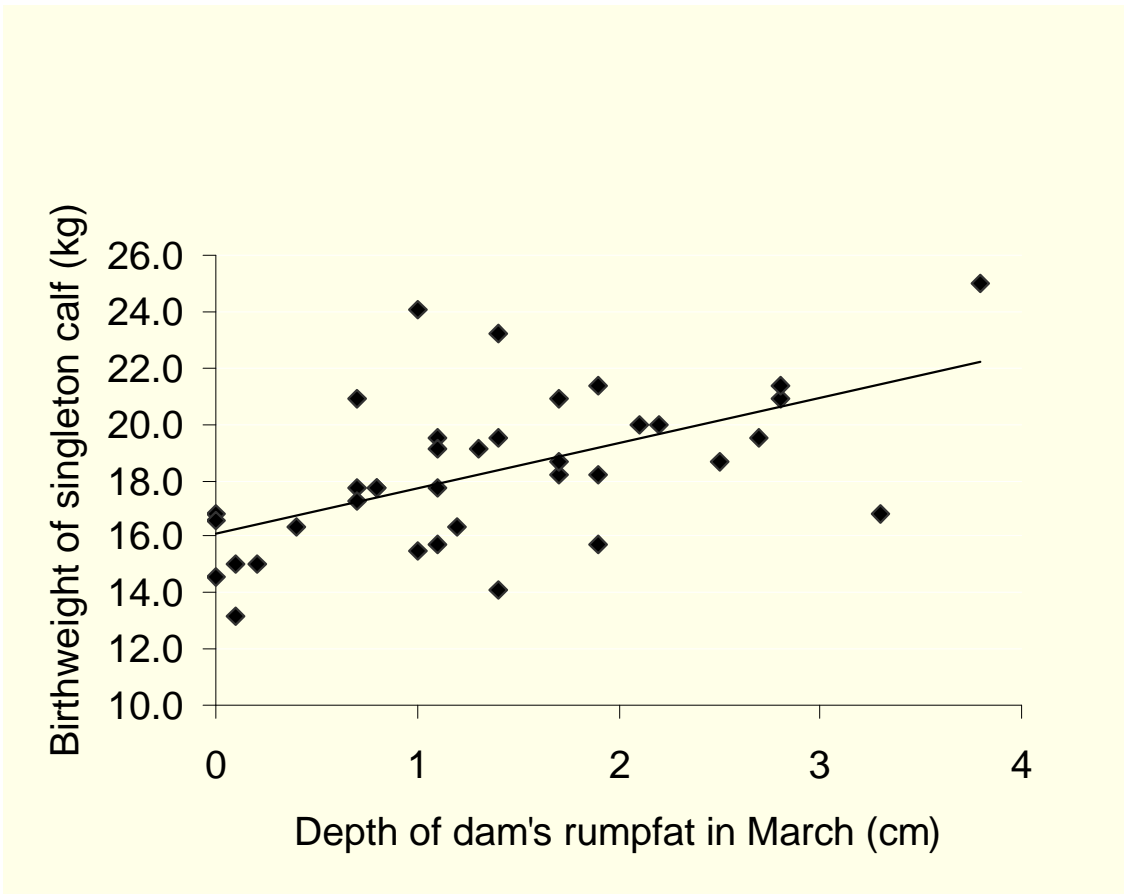
Figure 4 Relationship between singleton calf birth weight in May and depth of dam's rump fat in March, central Unit 20A, 1996 and 1997 data combined, $P = 0.0003$, slope = 1.60, $R^2 = 0.29$
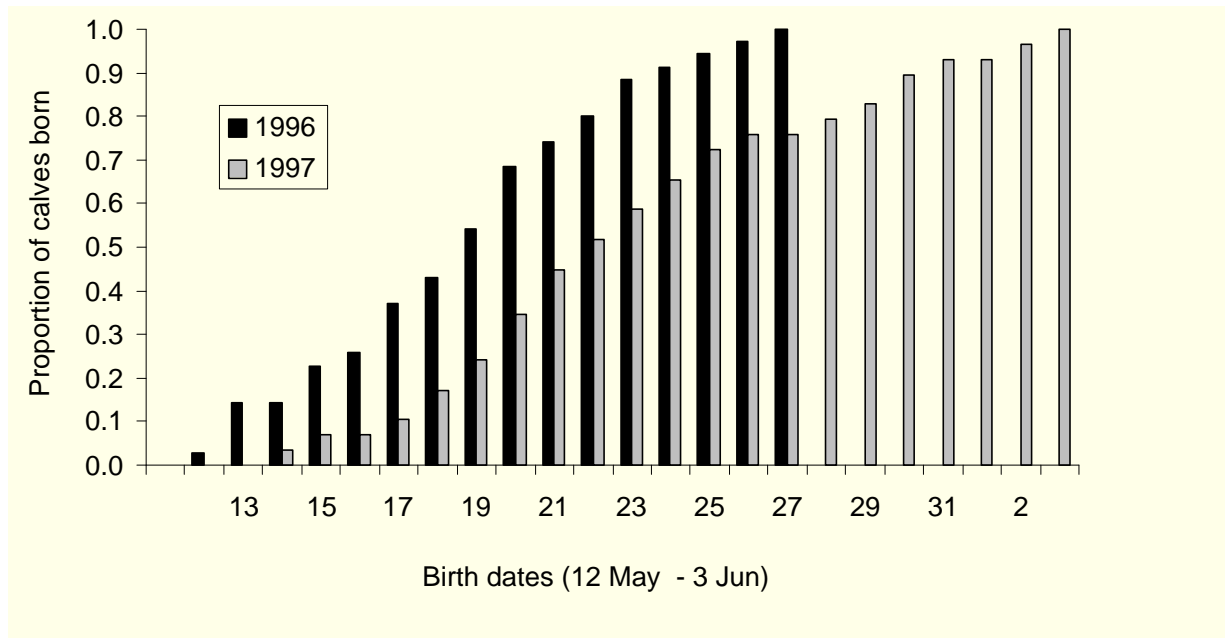
Figure 5   Cumulative proportion of moose calves born to radiocollared dams during calving seasons 1996 and 1997, central Unit 20A
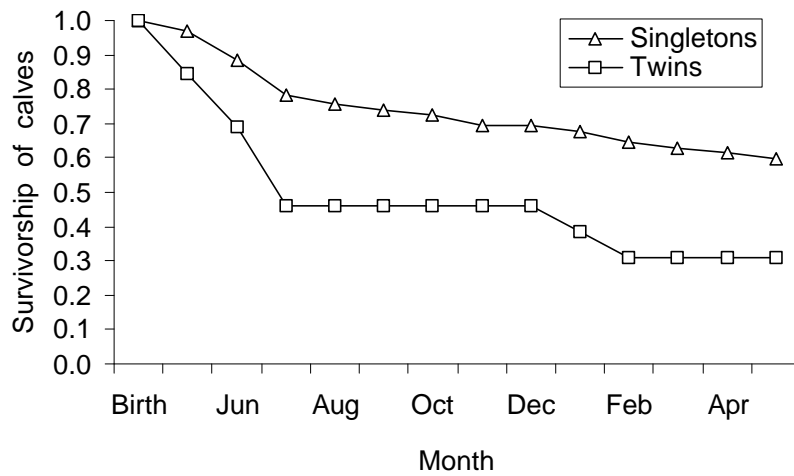
Figure 6 Survivorship of radiocollared singleton ($n = 70$) and twin ($n = 13$) moose calves born in the 1996 and 1997 cohorts, Unit 20A. Survivorship functions were significantly different ($P<0.05$), log-rank test.
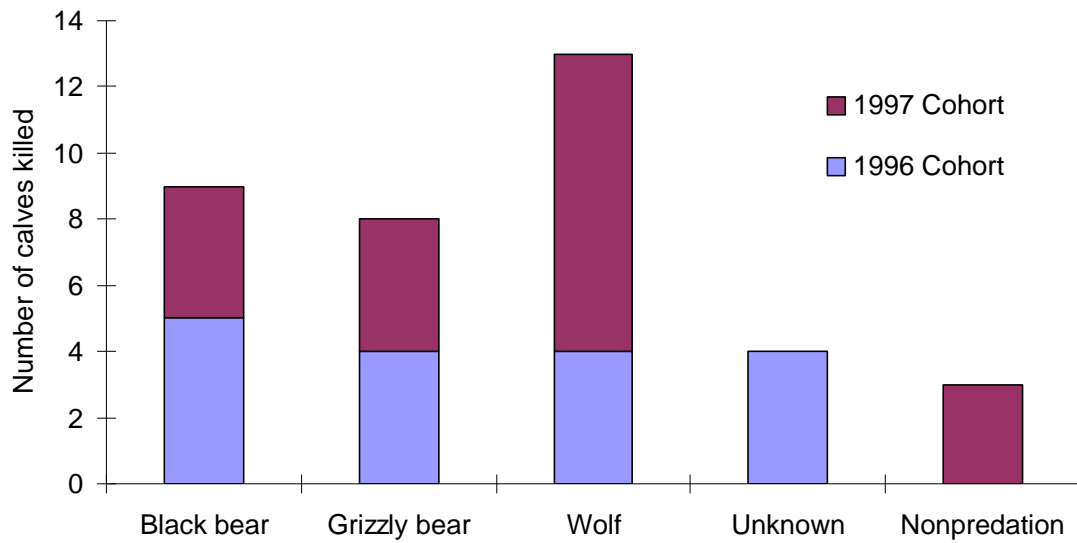
Figure 7 Causes of death among 37 radiocollared moose calves that died in the 1996 and 1997 cohorts in central Unit 20A. Nonpredation mortality included 1 calf that died from drowning/exposure (Sep–Oct), 1 calf that died from malnutrition (Feb), and 1 calf that died from injuries inflicted by a moose during the rut.

Tables

Table 1 Observed pregnancy rates of adult moose ≥4 years old in May in the Tanana Flats and adjacent Alaska Range foothills, 1996–1999, central Unit 20A

| | Pregnancy rates (%) of moose ≥4 years old in May | | | | | |
| | Tanana Flats | | Alaska Range Foothills | | Combined areas | |
Year	*%*	*n*	*%*	*n*	*%*	*n*
1996	89	19	81	21	85	40
1997	55	20	95	19	74	39
1998	79	19	79	19	82	38
1999	80	15	79	14	79	29
Combined years	75	73	84	73	80	146

Table 2 Twinning rates among parturient radiocollared moose ≥4 years old in May compared with rates among random parturient moose ≥3 years old observed on late May surveys in the Tanana Flats, 1996–1999, central Unit 20A

| | Twinning rates (%) among parturient moose in May | | | | |
| | Daily observations of radiocollared moose ≥4 years old | | Random moose on standard surveys (≥3 years old) | | |
Year	*%*	*n*	*%*	*n*	
1996	32	34	18	40	(May 26)
1997	10	29	12	26	(May 21)
1998	20	30	7	55	(May 26, 30)
1999	3	33	3	64	(May 25, 26)
Combined years	17	127	9	185	

Table 3 Average rump-fat depths of adult female moose from the Tanana Flats and adjacent Alaska Range foothills, March 1996 and 1997, central Unit 20A

| | Tanana Flats | | | | | | Alaska Range foothills | | | | | |
| | 1996 | | | 1997 | | | 1996 | | | 1997 | | |
Parameter	$\bar{x}$	*s*	*n*	$\bar{x}$	*s*	*n*	$\bar{x}$	*s*	*n*	$\bar{x}$	*s*	*n*
Adult rump fat at midpoint (cm)	0.7[a]	0.5	20	0.2[ba]	0.3	18	0.5	0.4	22	0.7[b]	0.4	12
Adult rump fat at maximum (cm)	1.7[c]	1.1	21	0.5[dc]	0.6	18	1.4	1.0	22	1.7[d]	0.7	12

[a]Difference significant (*P* = 0.0004), *t*-test.
[b]Difference significant (*P* = 0.0004), *t*-test.
[c]Difference significant (*P* = 0.0001), *t*-test.
[d]Difference significant (*P* = 0.0001), *t*-test.

Table 4 Average rump-fat depths for pregnant and nonpregnant adult female moose, March 1996 and 1997, central Unit 20A

Status	Rump fat at midpoint (cm)			Rump fat at maximum (cm)		
	$\bar{x}$	s	n	$\bar{x}$	s	n
Pregnant adult cows	0.55[a]	0.43	64	1.44[b]	0.99	65
Nonpregnant adult cows	0.05[a]	0.11	8	0.33[b]	0.57	8

[a]Difference significant ($P = 0.0001$), t-test for unequal variances.
[b]Difference significant ($P = 0.001$), t-test for unequal variances.

Table 5 Average rump-fat depths in March from moose dams with singleton versus twin newborn calves in May 1996 and 1997, central Unit 20A

Status	Rump fat at midpoint (cm)			Rump fat at maximum (cm)		
	x	s	n	x	s	n
Cow with singleton	0.51[a]	0.42	42	1.29[b]	0.93	42
Cow with twins	0.81[a]	0.43	11	2.16[b]	0.92	12

[a]Difference significant ($P = 0.0409$), t-test.
[b]Difference significant ($P = 0.0058$), t-test.

Table 6 Average weights of female calves 10 months old in the Tanana Flats and adjacent Alaska Range foothills, March 1997–1999, central Unit 20A

Year	Weights of 10-month-old female calves (kg)								
	Tanana Flats[a]			Alaska Range foothills[a]			Combined Areas		
	x	s	n	x	s	n	x	s	n
1997	154.2	25.0	17	164.5	24.7	17	159.2	25.0	34
1998	150.9	20.9	20	169.4	19.1	20	160.2	21.9	40
1999	158.9	17.7	18	178.0	18.9	19	168.7	20.5	37
Combined years	154.6	21.17	55	170.8	21.2	56	162.8	22.6	111

[a]Moose weighed in the Tanana Flats were significantly lighter than moose in the Alaska Range foothills ($P = 0.0001$, F value = 16.00, Type III sums of squares, SAS software).

Table 7 Average birth weights for singleton and twin newborn moose, 1996 and 1997, central Unit 20A

| | Singleton birth weights (kg)[a] | | | | | | Twin birth weights (kg)[a] | | | | | |
| | Males[b] | | | Females[b] | | | Males | | | Females | | |
Year	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
1996[c]	18.4	3.0	9	16.4	2.6	17	14.1	2.4	4	13.5	1.4	6
1997[c]	17.6	2.2	15	16.2	2.3	21				14.4	1.1	3
Combined (1996–1997)	17.9	2.5	24	16.3	2.4	38	14.1	2.4	4	13.8	1.3	9

[a]Male singletons weighed significantly more than male twins in 1996 ($P = 0.0294$) and combined 1996–1997 ($P = 0.0092$). Female singletons weighed significantly more than female twins in 1996 ($P = 0.0174$) and combined 1996–1997 ($P = 0.0049$), t-test.
[b]Male singletons weighed significantly more than female singletons in 1996 ($P = 0.0893$), 1997 ($P = 0.0779$), and combined 1996–1997 ($P = 0.0144$), t-test.
[c]No significant difference between 1996 and 1997 birth weights ($P > 0.2$) within sex or sibling status, t-test.

Table 8 Annual survival rates of radiocollared moose, 1996–1997 through 1998–1999, central Unit 20A

| Year | Annual survival rates (%) | | | | | |
| | 1996–1997 | | 1997–1998 | | 1998–1999 | |
	%	*n*	*%*	*n*	*%*	*n*
Calves (0–12 months)	56	49[a]	52	53[b]	--	--
Yearlings (12–24 months)	--	--	87	41	67	47
2-year-olds (24–36 months)	--	--	--	--	100	24
Adults (≥ 36 months)	88	44	93	41	79	40

[a]Maximum numbers of calves at risk at any time, 42 radio collars deployed in May 1996 and 29 in March 1997.
[b]Maximum numbers of calves at risk at any time, 41 radio collars deployed in May 1997 and 29 in March 1998.

Table 9   Moose population modeling outputs using average values for moose composition, numbers, mortality and productivity in Unit 20A during 3 low snowfall years, 1996–1997 through 1998–1999

| | Moose | | | |
	Adults ≥24 months old	Yearlings 12–24 months old	Calves 0–12 months old	Totals
Precalving in Year 1	8520	1942	0	10,462
Calves produced	0	0	4816	4816
Killed by wolves	662	313	870	1845
Harvested	678	100	0	778
Killed by grizzly bears	66	45	535	646
Killed by black bears	0	45	603	648
Killed by other factors	199	45	201	445
Remaining at precalving in Year 2	6915	1394	2603	10,912

APPENDIX A Relationships between blood-serum variables and depth of rump fat in Alaskan moose

Abstract: We studied the relationship between maximum depth of rump fat determined from ultrasound measurements and 22 blood values for Alaskan moose (*Alces alces gigas*) by sampling 38 pregnant, adult females. Moose were immobilized, and blood was drawn simultaneously with the determination of depth of rump fat during 1–4 March 1996. Multiple-regression models were used to detect relationships between blood-serum variables and depth of fat. Four of 22 blood-serum variables were removed to control for multicollinearity. Remaining variables were regressed against induction time ($\bar{X}$ = 6.1 min, SD = 4.4 min). Glucose, sodium, and blood urea nitrogen were correlated with induction time (R^2 = 0.27, P = 0.010) and likely represented a response to handling; these blood values also were removed from the final regression model. Mallow's Cp statistic indicated the most appropriate regression model included only 2 variables. Creatinine ($\bar{X}$ = 2.08 mg/dl, SD = 0.26 mg/dl) and aspartate aminotransferase (AST) ($\bar{X}$ = 79.10 U/l, SD = 13.61 U/l) met all necessary assumptions and explained a portion of the variability observed in fat depth ($\bar{X}$ = 1.5 cm, SD = 1.0 cm). Thus, our final model was: maximum depth of rump fat = 0.28 + 1.68 (creatinine) –0.03 (AST). This model was significant (P = 0.0002) and accounted for 33.7% (R^2) of variability observed in fat depth. Partial regression coefficients for creatinine and AST were 0.222 (P = 0.0025) and 0.150 (P = 0.006), respectively, and indicated that creatinine we slightly more influential than AST in the model. These blood variables may provide insights into the predicted condition of moose and the response of moose to environmental conditions. A model using blood variables thought to be indicators of physical condition (protein, phosphorous, and calcium) did not explain significant variation in maximum depth of rump fat.

APPENDIX B Effects of birth weight on growth of young moose: Do low-weight neonates compensate?

Abstract: We studied the relation between birth weight and 3 measurements of body size in 10 female Alaskan moose (*Alces alces gigas*) at 10 months of age in a population where density was high (1.3 moose/km^2), compared with other areas of interior Alaska. Our study area was located in interior Alaska, USA, between the Tanana River and the Alaska Range, directly south of Fairbanks. We captured newborn (<5 days old) moose from helicopters, weighed them, and then affixed radiocollars during 14 May–3 June 1997. These same moose were immobilized with a dart-gun fired from a helicopter, weighed, and measured during 13–16 March 1998. We used regression analyses to investigate the relationships between weight at birth and weight, metatarsus length, and total body length for recaptured individuals at 10 months of age. Positive linear relationships existed between each measure of size at 10 months and weight at birth, and were highly significant (*P*<0.02). Further, birth weight explained significant variability in each of those 3 measurements (r^2=0.63, 0.64, 0.53, respectively). Our results support the hypothesis that neonates with lower weights at birth in this population did not exhibit compensatory growth and remained among the smallest individuals in their cohort, at least during their first 10 months of life.

APPENDIX C Life-history consequences of maternal condition in Alaskan moose

KEECH MA, RT BOWYER, JM VER HOEF, RD BOERTJE, AND BW DALE. IN PRESS. *Journal of Wildlife Management.*

Abstract: We studied characteristics of life-history of Alaskan moose (*Alces alces gigas*) including the effects of maternal condition of adult females on survival and physical condition of young during their first year-of-life. We also examined the relation between maternal condition and reproductive parameters of individual adult moose. We found that females in better physical condition, as indexed by rump-fat thickness, had higher rates of pregnancy, gave birth to more twins, and produced young with higher birth masses than did females with less rump fat. Expected time-to-death for individual young increased as birth mass increased and decreased with increasing birth date and litter size. Our results indicated maternal condition influenced subsequent variables associated with birth, which ultimately influenced future survival of offspring. Timing of parturition also occurred earlier for individual females with greater rump-fat thickness. That outcome suggested that timing of parturition was the result of environmental factors acting on females prior to birth.